TP-71-8000 January 1971

Technical Proposal
for
"Automated Coordinate Display System"

Prepared in Response To: RFP #PIC-02-71(50062)

Prepared by

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Prepared for United States Government

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I. <u>TASK ABSTRACT</u>

In response to NPIC RFP #PIC-02-71(50062), the is submitting this proposal for the analysis and design of an Automated Coordinate Display System and for the fabrication and evaluation of a breadboard model of that system. The ultimate system will provide for the measurement of photo image coordinates employing an existing 1540 Light Table with add-on cursor and encoder, the transformation of image coordinates into ground coordinates in real time utilizing an online digital computer, and the digital display at the light table of those computed ground coordinates. Since the construction of the Automated Coordinate Display System is well within the present state-of-the-art, the major effort in the proposed study and development program will be to define the most cost effective approach consistent with the required accuracy.

Cost Summary:

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Direct Labor

Overhead

Materials

Travel

 ${\tt Computer}$

G & A

Total Estimated Cost

Fee

Total Estimated Cost plus Fixed Fee

25X1

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II. INTRODUCTION

In the interpretation of reconnaissance imagery, the interpreter frequently locates the targets which he has detected by reference to maps. By correlating the imagery with the detail on the map, he is able to read out the target coordinates and report them. When overlapping imagery is available, as in a mapping mission, keeping track of location from photograph to photograph is not too difficult, although it does require numerous map sheets and the attendant handling. When there are gaps in the coverage due to cloud covered areas or the camera being turned off for a time, the time required for relocation on the map will go up considerably. With new reconnaissance systems, the trend is toward ever increasing amounts of film and an ever increasing urgency for rapid reporting of targets and activity. In order to avoid a bottleneck in the intelligence cycle, without adding huge amounts of interpreters and light tables, it is desirable to investigate ways of automating the target position readout part of the problem.

Recent improvements in navigation system accuracy coupled with auxiliary data recording on the reconnaissance film offer a potential for automating this process of target location. The description to follow is based on the assumption that sufficient navigation data are available to locate the photo corners, fiducial marks, or other image points on each frame of photography in ground coordinates. This aspect is discussed in more detail in the technical discussion part of the proposal.

Viewing of reconnaissance imagery is normally done on a light table and this will form an excellent base for determining the photo coordinates of the target with respect to the fiducial marks or any known point on the film. Figure 1 is a sketch showing the major components required to compute and display the target coordinates. A movable cursor coupled to encoders will provide a digital measurement of a point or points on the table. Attached to the cursor will be a hand switch. Operation of the hand switch will cause the photo coordinates to be entered into the computer. Auxiliary data or identifiers will also be entered at this time from an auxiliary data panel which will contain thumbswitches or buttons for entering

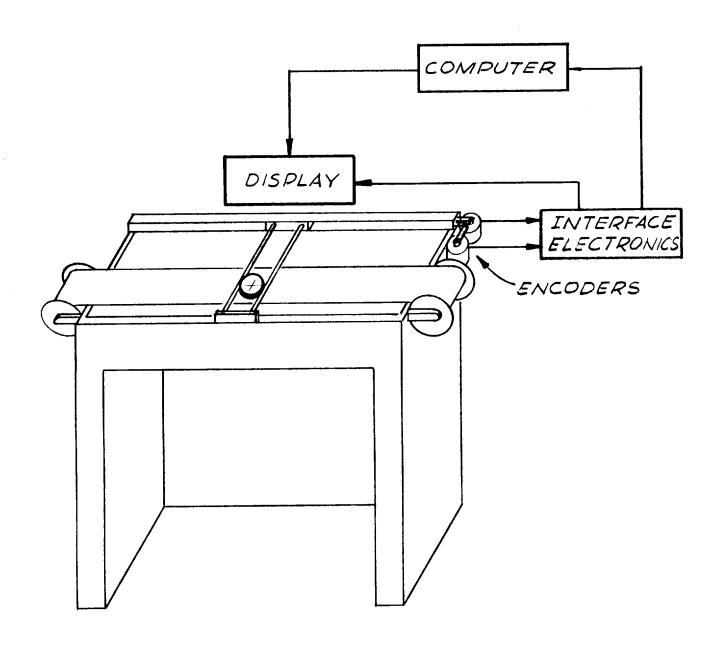


FIGURE 1 - DIGITIZING LIGHT TABLE

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frame number and fiducial or target identifiers. Navigation data can be entered from the auxiliary data panel for each frame, or it can be pre-entered into the computer memory for an entire mission and called up as needed by the program. This aspect will be studied in some detail in the program to determine the most cost effective approach.

The film can easily be constrained to follow film guides on the table, and thus the y coordinate of the film edge or fiducial mark will not appreciably change from frame to frame. In addition, this same constraint will prevent rotation of the film on the table. These constraints will allow the entry of a single reference coordinate for each frame. Once the reference system is set up, the operator will then place the cursor over a target and enter its photo coordinates by pressing the hand switch. The computer program will compute the ground coordinates of the target and display them on the operator's display. Alternate arrangements are easily obtainable for printing out the coordinates on a teletype or line printer. They could also be stored on magnetic tape if desired.

Other modes of operation are possible. If the ground coordinates of a target previously detected are known, then, after entry of the reference data, the computer can output the photo coordinates where the interpreter should expect to find that target on the new coverage. By causing his table coordinate display to equal the output display, he should find the target under his cursor.

The state-of-the-art today will easily permit the construction of the Automated Coordinate Display System. The major thrust of the proposed study and development program will be to define and develop the most cost effective approach consistent with the required accuracy.

qualified to conduct the subject study and development program. Our current staff includes mathematicians, photogrammetists, computer programmers and engineers whose specific backgrounds and experience relate directly to the proposed study tasks. In addition, we have recently completed the successful development of a digitizing light table interfaced to a small digital computer, and are thoroughly familiar with the hardware and software techniques involved.

III TECHNICAL DISCUSSION

The following paragraphs outline the procedures 25X										
proposes to follow in the analysis, design, fabrication, and evaluation of an										
Automated Coordinate Display System for the rapid determination of the										
geographic coordinates of ground points imaged on aerial photography, in										
particular photography produced by the prime (panoramic) cameras 25X										
(The utilization of photography from other systems will also be										
considered.) The task is divided into two phases, a study phase and a breadboard										
phase, and each phase is divided into two tasks, a systems analysis task and										
system design task under the study phase and a fabrication task and evaluation										
task under the breadboard phase.										

1. Phase I - Study Effort

1.1 Task I - Systems Analysis

The Systems Analysis includes the establishment of system requirements, the analysis of the sensor system, the establishment of the system error budget and the analysis of various data reduction techniques. The Automated Coordinate Display System will consist of light tables, each equipped with a cursor for measuring photo image coordinates and a digital display for the readout of the corresponding ground coordinates (latitude and longitude), and a digital computer for the real time transformation of the image corrdinates into ground coordinates. Two general techniques will be considered for the measurement of image coordinates and subsequent transformation of those coordinates into ground coordinates: (1) The measurement of an image point and one reference point, the ground coordinates of the image point then being determined by a single ray intersection employing camera position and attitude data; and (2) the measurement of an image point and four reference points whose ground coordinates are known, the ground coordinates of the image point then being determined by a two-way interpolation.

1.1.1 System Requiremen	ts
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Catom +1	In order to properly design the Automated Coordinate Display
rate will	e requirements of that system must first be established. Production constitute a major requirement of the system. That is, the system
	modate in a minimum amount of time all of the photography which
	tent this will also govern the choice between the use of one or more
	computers handling multiple light tables, and the use of the in-
	AC 494 computer.

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1.1.3 System Error Budget	
Two approaches may be taken in establishing an error budget for	
the Automated Coordinate Display System: (1) Establish the maximum accuracy required of the system or (2) establish the maximum accuracy obtainable from	
the system. Hopefully, a higher accuracy is obtainable than is required. Both approaches will be thoroughly examined by	25X
The accuracy required of the system will depend upon the use to	
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which	the	system	is	to be	put.	For	example	, if	the	syste	m is	t o	be	employed	25)

		25X1
1.1.4	Data Reduction System Analysis	

1.1.4.1 Data Reduction Technique Study

The purpose of the data reduction system analysis will be to design optimum data reduction software for the Automated Coordinate Display System. As noted earlier (Paragraph 1.1) two general tecniques will be considered for data reduction: (1) a two-way interpolation and (2) a single ray intersection.

The two-way interpolation requires the measurements of the image point whose ground coordinates are desired and of four reference points whose ground coordinates are known. The four reference points could be the four scan angle marks nearest the image point of interest. No information is required concerning the camera, e.g., focal length, position, attitude, etc., nor is any special alignment of the film on the light table required. The two-way interpolation, however, is not rigorous since it assumes that scale changes are linear between any two of the four reference points employed for the interpolation. However, it may be valid to consider them linear if the four reference points are sufficiently close together because of the low accuracy required. As a first step in the analysis, then, will determine in what form, if any, ground coordinates of reference points are given (Paragraph 1.1.2). For example, will the ephemeris give the ground coordinates of scan angle marks

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the easiest way of entering those data into the computer? If, finally, the two-way interpolation should prove feasible, a study would be performed to determine how close together the reference points must be to satisfy the accuracy requirements.

The single ray intersection requires the measurements of the image point whose ground coordinates are desired and of one reference point, e.g., a scan angle mark, but assumes that the film is aligned within certain tolerances (to be determined) on the light table. The ground coordinates of the reference mark are <u>not</u> required, but the position and attitude of the camera, the camera focal length, the scan rate, and other sensor data will be required. The single ray intersection can be completely rigorous if the ground elevation is known. However, because of the relatively lax accuracy requirements it may be possible to degrade the formulation of the single ray intersection, e.g., by considering a spherical or even flat Earth instead of a spheroidal Earth.

will, of course, determine the optimum formulation for the single ray intersection meeting accuracy requirements. The form and format of all data required of the single ray intersection will then be determined.

If both the two-way interpolation and the single ray intersection techniques should prove feasible, it will be necessary to determine which technique is most suitable or effective in satisfying the requirements of the Automated Coordinate Display System. A study will be made of the computer requirements of each of the two formulations to determine which may be most easily implemented and which provides the most rapid real time response (if significant). The interpreter-computer interface, in terms of the manner in which the various data are entered into the computer, will be studied to determine which of the two techniques may be most easily and rapidly employed by the interpreter.

1.1.4.2 Review of Existing Programs

A number of techniques, mathematical models, and computer programs

capable of determining ground coordinates from image measurements already	25X1						
exist at NPIC, for example, the UGDIP program which, for single photographs,							
employs a rigorous version of the single ray intersection.							
will review all of these existing techniques and computer programs in order							
to determine which, if any, would be suitable for use, with or without							
modification, in the Automated Coordinate Display System.							

1.1.4.3 Optimum Computer Program Design

As a result of the study outlined in Paragraph 1.1.4.1, an optimum formulation for determining ground coordinates from photo image measurements will have been established. The review of available programs at NPIC (Paragraph 1.1.4.2) will indicate the existence there of programs based upon that optimum formulation or a formulation sufficiently similar to meet the requirements of the Automated Coordinate Display System. will then prepare complete program specifications suitable for the preparation of a production computer program, including all input-output formats which are required for interfacing with the interpreter, the light table measuring device, and the light table display device. The specifications will be based either on the programs available at NPIC, if suitable, or upon the formulations developed by (A computer program, suitable for the determination of ground coordinates from image coordinates but including only rudimentary input-output capabilities, will be prepared as a part of the construction of the breadboard device in Phase II of this proposal.)

1.2 <u>Task II - System Design</u>

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The practical implementation of the system requires studies in three basic areas. These studies are discussed below, and consist of (a) mechanical analyses for coupling measuring encoders to the light table, (b) electrical analyses to determine the optimum computer interface, and (c) computer trade-off analyses for maximum cost effectiveness.

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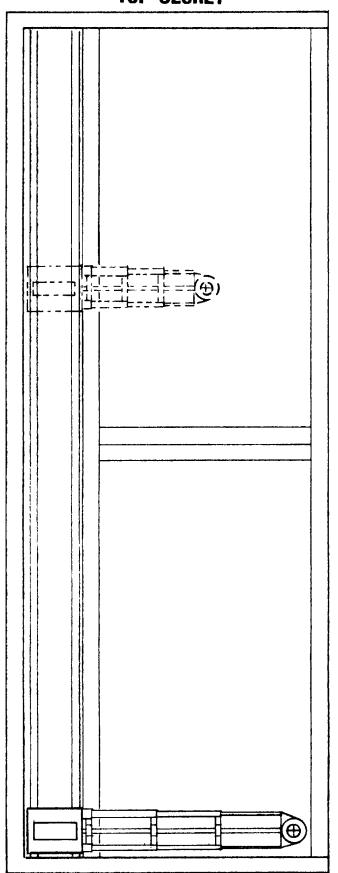
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1.2.1 Mechanical Design Studies

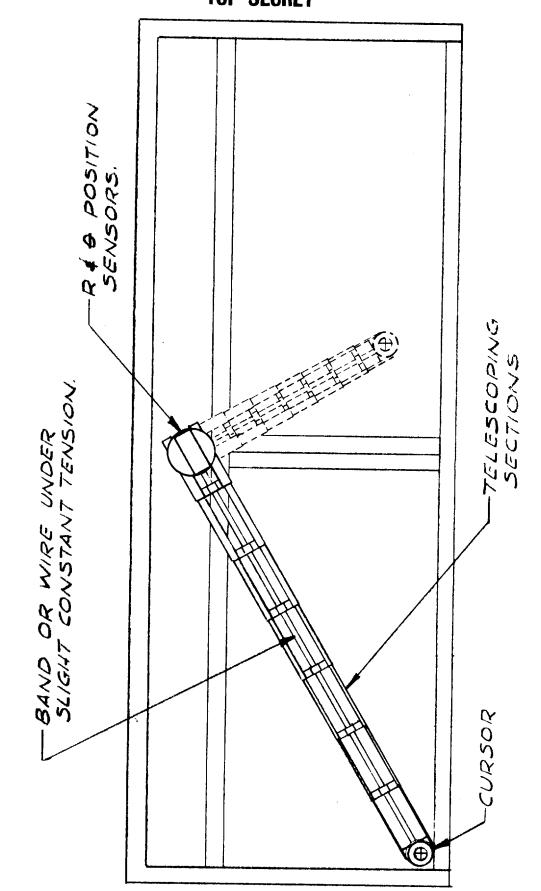
The most desirable approach for coupling a cursor and encoders to the 1540 light table would be one which would require a minimum amount of modification to the light table itself. An ideal approach would be one in which no modifications at all were required; such as a simple clamp-on or bolt-on assembly. If the latter were possible, it would be a simple matter to move the encoder assembly from table to table if the need arose. This approach would probably also minimize the cost. The mechanical design study task will be directed toward finding such an approach if at all possible.

An inspection of the pictures of the 1540 light table shows that the addition of a standard X, Y carriage may be somewhat difficult due to the limited space and the desire not to interfere with the normal operation of the table. Figure 1 (Page 3) shows schematically the addition of a standard X, Y carriage to the light table and the block diagram of the other system components. Figure 2 shows a slightly different mechanical arrangement in which no modifications would be required at the front of the table and the cursor assembly could be removed almost completely from the light table surface when desired.

Another alternate approach which appears at this time to offer great promise is a cursor on an extendable arm pivoted about a point near the rear center of the table. By encoding the length and angle of the cursor, the table measurements would be encoded in polar coordinates. Since there is no need for an X, Y display, and since the data will be fed into a computer anyway, it makes little difference whether the target measurements are made in a rectangular or a polar coordinate system. Figure 3 is a sketch showing one possible arrangement of components. Figure 4 is yet another mechancial arrangement of the same idea. There are undoubtedly many other ways of mechanizing this approach, and the Phase I study will investigate several alternative approaches which are consistent with the required accuracy, reliability and cost objectives.



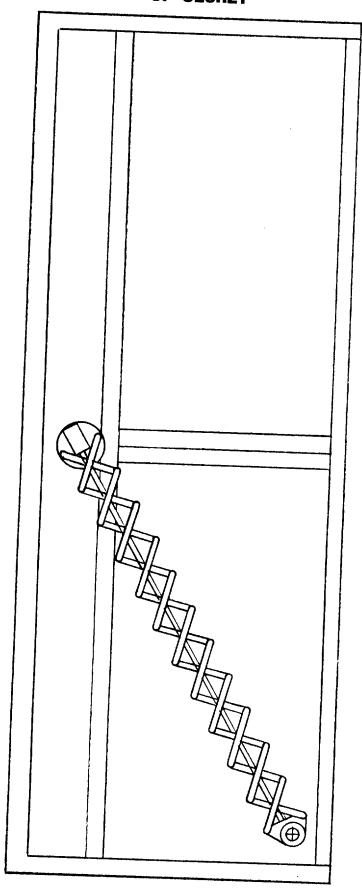
SYSTEM WITH -Y COORDINATE S'ELESCOPING ARM 0 FIGURE



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FIGURE 3:

R-O COORDINATE SYSTEM WITH TELESCOPING ARM.



FIGURE

Still another interesting approach has recently been developed at which could possibly provide a low cost, reliable solution to the encoding of table coordinates. This technique is illustrated in Figure 5, and consists of a hand held cursor containing a spark gap or other sound source. Sound tranducers are placed at two other positions on the table. The system operates as a ranging device by measuring the time required for the sound to travel from the cursor to each pickup. Obviously such a device could be installed with a bare minimum of modification to the light table. Things which must be considered are accuracy, effects of temperature, and interference effects from the general noise background.

1.2.2 Electrical Design Studies

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The preliminary design of the electronic subsystem will depend somewhat on the encoding technique chosen; however, most of the functions to be performed will be independent of the encoders, and these studies can proceed in parallel. One thing to be seriously considered early in the study program is the amount of electromagnetic interference to be expected. The high intensity light sources in the tables are often a source of intense radio frequency energy due to the high voltage operation and the methods of luminous intensity control employed. In addition the tables are equipped with film drive motors and blowers which can also be a source of noise. Since it could be quite expensive to EMI proof the tables, the electronic design of the digitizing system should be made as immune to noise as possible. Further assurance can be gained by furnishing a table to the study contractor early in the program for test and evaluation.

Figure 6 is a functional block diagram showing the interface between the light table and a digital computer. For this study only that portion of the system shown enclosed in heavy dashed lines need be mechanized and tested. However the remainder of the system will be studied and a preliminary design of the complete interface to a representative digital computer will be performed.

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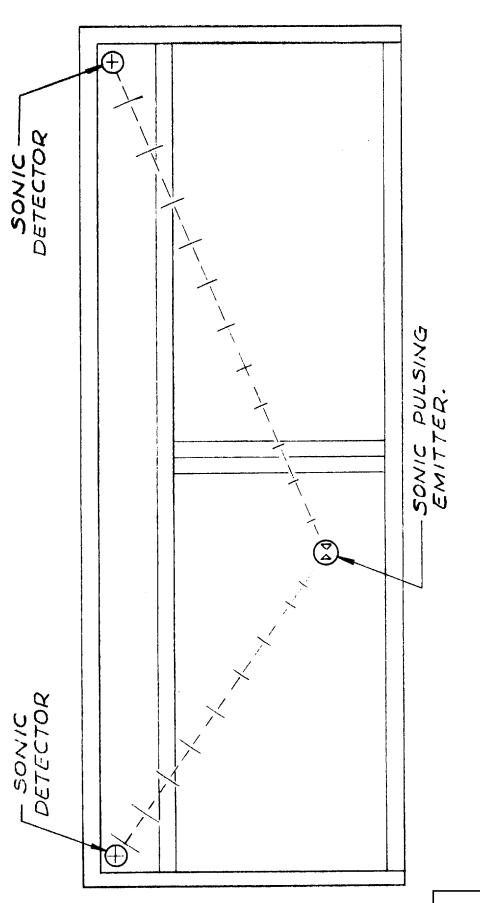
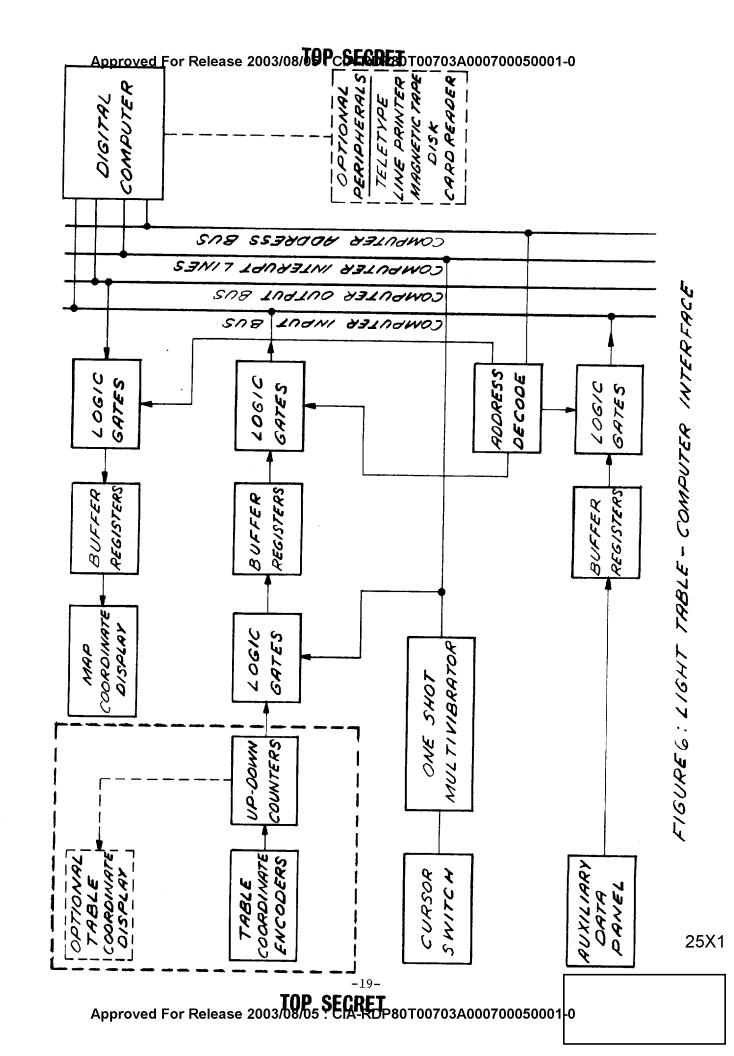


FIGURE 5: SONIC RANGING SYSTEM

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An alternative interface, to mate with the customer's Univac computer, will also be studied for cost and performance comparison. In all probability, many of the functions to be performed will be identical; however, a detailed analysis is necessary before any conclusions can be drawn.

In Figure 6, the table coordinate encoders will generate count pulses which will be accumulated in the up-down counters. The state of the counters at any time represents the table coordinates in whatever coordinate system is chosen. For the purpose of demonstrating a workable concept, it will be sufficient to read out these counters into a display and record the coordinates for manual input into a general purpose computer. The remaining functions are necessary for an "on line" type of operation. In this later mode, operation of the cursor switch will generate an interrupt pulse to the computer and simultaneously strobe the contents of the up-down counters into buffer registers. This action, in effect, stores the coordinates until the computer program has time to read them into the computer memory, and informs the computer that the particular table has data ready for entry. higher priority interrupt is being serviced, the computer will jump to the interrupt subroutine assigned to this particular interrupt and proceed to strobe into assigned memory locations the contents of the buffer registers for the coordinates and the auxiliary data. The computer will then calculate the ground coordinates of the target, output them in the proper form to the map coordinate display, and proceed to service the next lower priority interrupt from some other device.

Figure 7 is a picture of the many mini-computers on the market today. Table 1 is a brief summary of some of the important specifications.

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- 1. Word length 16 bits
- 2. Memory cycle time 1.0 microsecond
- 3. Memory 4 thousand to 16 thousand words
- 4. Interrupt Expandable to 16 levels

- 5. Input/output 16 line input bus

 16 line output bus

 8 line address bus

 1 line input strobe

 1 line output strobe

 1 external sense line

 up to 16 interrupt lines
- 6. Peripherals Card Reader
 Available Teletype
 Line Printer
 Magnetic tape
 Magnetic disk
 Plotter

TABLE 1

During the study program the computer requirements will be defined, and a comparison will be made of several computers on the market which satisfy these requirements.

Another important factor in the study is the type and location of the map coordinate display. Many numerical display devices are available on the market today which are computer compatible. The important points to be considered in the study are the high ambient light level in the vicinity of the light table and the need for high reliability. Size is also important since a large package would severely limit the possible location of the display. These factors will all be considered and a suitable numerical display will be recommended.

One of the requirements of the RFP is "the automated coordinate display system will have the option to be used with a microstereoscope while viewing imagery." This requirement can be satisfied in various ways and the study effort will seek to determine the least complicated approach.

The techniques range all the way from a separate set of encoders attached to the microscope carriage, to a simple instruction to the operator to align the microscope reticle with the cursor reticle for data entry.

1.2.3 Computer Studies

The choice of a computer for an ultimate system will be determined to a large extent by the program complexity required to compute the ground coordinates to the required accuracy. This part of the study program will be devoted to an evaluation of the programs already developed and in the customer's inventory and their applicability to the task at hand. It may well turn out that the program can be simplified so as to require fewer computational steps than at present. Once the structure and accuracy of the program is defined, a determination of the required computer word length and memory size can be made. The appropriate execution speed for the computer will be determined from the required response time and from the number of light tables to be supported. Part of the study will yield a recommendation for the optimum number of tables to be interfaced to a single computer. A study of the computer configuration as a part of the total system design will lead to the recommendation of a computer which can perform in a cost effective manner in the system.

The study will also include an evaluation of the capabilities of the Univac 494 for this application. In addition, a comparison of system cost and performance will be made between a system with the Univac 494 and a system with a small dedicated computer.

2. Phase II - Breadboard Construction and Evaluation

At the completion of the Phase I study effort, and with the concurrence of the contracting officers technical representative, a demonstration breadboard system will be designed and fabricated. The demonstration breadboard will include the detailed design, fabrication, assembly, and test of the

selected table coordinate encoding system and the attachment of this system to a customer supplied 1540 light table. The electronic package accompanying the encoder will be sufficient to display the table coordinates in the selected table coordinate system.

As part of the Phase I study, it will have been determined just what auxiliary data the operator will have to enter along with the coordinate data. A keyboard for entry of these data will be fabricated for evaluation purposes and located on the light table. The map coordinate display will also be designed, fabricated, and mounted on the light table.

The breadboard system will be tested for accuracy, reliability, and operator acceptance. The evaluation of the total concept will involve use of the breadboard to make image measurements, input of these measurements along with the necessary auxiliary data into the selected computer program in a general purpose computer, and printout of the computed target ground coordinates. Target coordinates computed in this way will be compared with answers determined by other methods such as maps, charts or other computational methods of known accuracy.

The preliminary design and estimated costs of a multiple table system will be one of the outputs of the Phase II effort.

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IV WORK STATEMENT

The contractor will perform the following tasks in support of the study and development of the Automated Coordinate Display System:

Phase I - Study Effort

Task I - Systems Analysis

1. System Requirements

The contractor will review the specific functions the system is to perform and materials the system is to handle and determine expected production rates and required throughput and turnaround times.

2. Sensor Analysis

The contractor will review sensor system parameters and determine the magnitude of errors anticipated in the various sensor subsystems, i.e., the main camera system, the attitude sensing system, the clock, and the ephemeris.

3. System Error Budget

The contractor will establish an error budget for the system employing rigorous error propagation techniques in order to determine the level of accuracy required of the mensuration equipment and computer software formulation.

4. Data Reduction System Analysis

The contractor will review mathematical analyses and computer programs at NPIC and will develop the optimum formulation for the

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computer software in terms of accuracy, response time, and interpreter-computer interface.

Task II - System Design

1. Mechanical Design Studies

The contractor will perform design studies aimed at optimizing the method of encoding photo coordinates on a 1540 light table. These studies will evaluate the relative merits of alternate methods in terms of accuracy, inertia, photo obscuration, reliability and cost. The contractor will perform a preliminary design of the selected technique.

2. <u>Electrical Design Studies</u>

The contractor will perform electrical design studies to define the photo coordinate readout and display subsystem, and to define the computer interface subsystem. These efforts will include an investigation of the electromagnetic interference characteristics of the 1540 light table, a preliminary design of the electronic subsystem for the photo coordinate readout, a preliminary design of the computer interface, and an evaluation of suitable display devices.

3. Computer Studies

The contractor will determine the computer requirements for automating the Coordinate Display System and make the necessary cost-performance trade off studies to recommend a computer for the operational system. These studies will include an evaluation of the use of the customer's Univac 494 as one of the alternatives. The contractor will determine the optimum number of light tables which can be interfaced with the recommended computer. The contractor will evaluate existing computer

programs for applicability to the system, and recommend an operational program.

Phase II - Breadboard Development

Task I - Breadboard Fabrication

The contractor will perform the detailed design, fabrication, and assembly of a breadboard system for attachment to the 1540 light table for target photo coordinate readout.

Task II - Computer Programming

The contractor will perform the necessary computer programming to demonstrate the feasibility of the selected approach. The computer program will accept coordinate data in the form generated by the breadboard equipment, combine these data with the auxiliary data which would be entered in an operational program, and calculate and print out the target coordinates which would ultimately be displayed to the light table operator. This program will use the equations and/or computational techniques which have been chosen as a result of the prior study effort.

Task III - System Evaluation

A series of tests will be performed using the breadboard system, operational photography, ground truth information, and the computer programs developed under Task II to evaluate the speed and accuracy of the techniques chosen.

The customer's and the contractor's interpreters will perform subjective evaluation of the system.

V <u>DELIVERABLE</u> ITEMS

- 1. Monthly progress reports will be furnished on or before the 15th of each month of the contract period. Four copies of each report will be furnished in the required format.
- 2. Five copies of a final report will be furnished. This report will include a complete description of the mathematical analyses performed during the study, a comparison of the accurancy achieved in the breadboard with the expected accuracy, and a complete evaluation of the breadboard performance. The report will also contain photographs, drawings, and specifications covering the breadboard design and development. A cost-effectiveness trade off analysis will be included to assess the value of further development.
- 3. Breadboard equipment developed under this contract will be delivered to the specified Government installation at the completion of the contract.

VI. PROJECT PERFORMANCE SCHEDULE

Month	Percentage Completion	Percentage Expenditures
1	25	22
2	50	43
3	64	60
4	78	78
5	92	92
6	100	100

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SCHEDULE MONTHS													,						
VIII. PROGRAM.		PHASE I - STUDY EFFORT	TASK I-SYSTEMS ANALYSIS	SYSTEM REQUIREMENTS	SENSOR ANALYSIS	SYSTEM ERROR BUDGET	DATA REDUCTION SYSTEM ANALYSIS	TASK II - SYSTEM DESIGN	MECHANICAL DESIGN STUDIES	ELECTRICAL DESIGN STUDIES	COMPUTER STUDIES	DESIGN REVIEW	PHASE II - BREADBOARD	TASK I - BREADBOARD FABRICATION	TASK II - COMPUTER PROGRAMMING	TASKIII-BREADBOARD GVALUATION	MONTHLY PROGRESS REPORTS	FINAL REPORT	

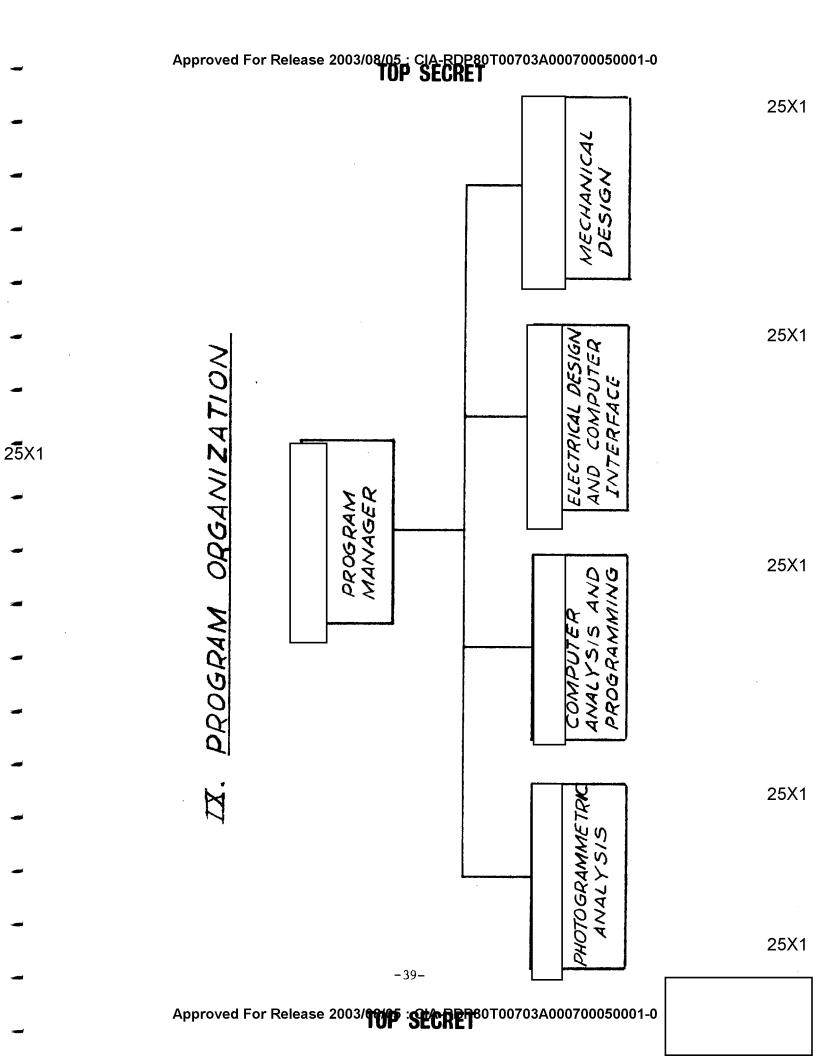
VIII. FINANCIAL CONSIDERATIONS

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IX. PROGRAM ORGANIZATION AND PERSONNEL QUALIFICATIONS

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